Available online at www.sciencedirect.com
SciVerse ScienceDirect
Procedia Engineering 47 (2012) 849 – 852
Procedia Engineering
www.elsevier.com/locate/procedia

Proc. Eurosensors XXVI, September 9-12, 2012, Kraków, Poland

Single-Mask Fabrication of Temperature Triggered MEMS Switch for Cooling Control in SSL System

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Abstract

A micro-electro-mechanical-system (MEMS) based, temperature triggered, switch is developed as a cost-effective solution for smart cooling control of solid-state-lighting systems. The switch (1.0x0.4 mm^2) is embedded in a silicon substrate and fabricated with a single-mask 3D micro-machining process. The device switches on at a designed temperature threshold (130°C) with a contact resistance of < 2 ohm, and switches off when the temperature drops below that limit. In this way, automatic control of a cooling system is possible, without any need of additional electronic components. The research is a part of the Enlight project.

Keyworkds: solid state lighting; temperature sensor; active cooling

1. Introduction

Solid-state-lighting (SSL), powered by LED, is a power-efficient technology for future lighting systems. During operation, approximately 70% of the electrical energy is converted to heat. The temperature rise in the LED, driver circuit and packaging is one of the main causes of failure [1]. In high power lighting systems, active cooling components are used to ensure sufficient temperature control [2,3]. In order to reduce the energy consumption of the active cooling system, smart control, e.g. switching on the active cooling only when the temperature exceeds a certain threshold, is applied. However, such solutions require many additional components, including a temperature sensor, readout/control circuits (together with its DC power supply), and even a high-voltage switch if required by the active cooling.

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doi:10.1016/j.proeng.2012.09.280

Consequently, this increases significantly the complexity and cost of the lighting system. It is therefore essential to look for a much simpler and cost-effective alternative solution for smart cooling control. In this paper we propose a temperature-triggered switch (TTS) (Fig.1) as a cost-effective alternative to achieve an automatic regulation of the active cooling.

2. Design

The temperature-triggered switch is integrated in the silicon substrate, which is used as a carrier for the LED chip, in order to accurately detect the temperature of the LED chip. A V-shape design is used to push the contact plate against the electrodes (Fig.1b) as the temperature increases. Different from traditional MEMS *V*-shape thermal actuators made from silicon beams [4], where a temperature difference by local heating is required, the TTS is able to actuate under a uniform temperature distribution. This is achieved by applying material with a high coefficient of thermal expansion (CTE) on the beams to generate a larger thermal expansion then the silicon substrate, under a uniform temperature distribution. The generated motion on the contact plate is a function of the substrate temperature increase.

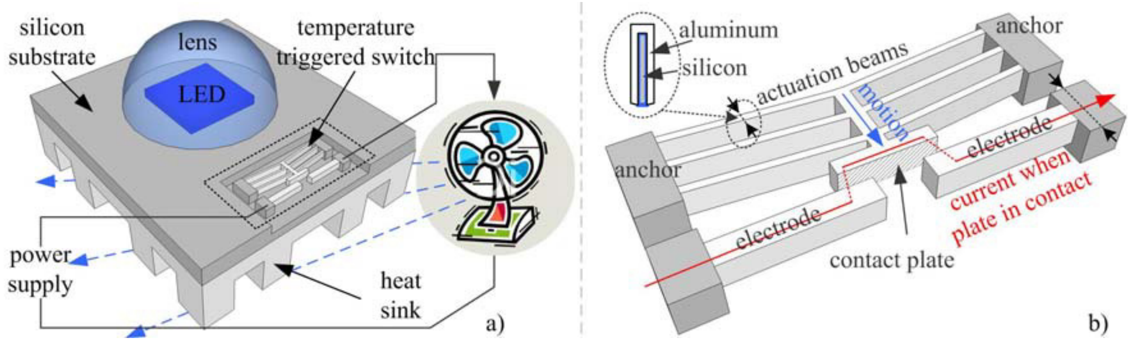


Fig. 1. (a) Schematic drawing of the proposed cooling system for LED. The TTS is embedded to detect the temperature of the substrate. It switches on the active cooling component, i.e. a fan, when the temperature exceeds a designed threshold. (b) Schematic drawing of the TTS, illustrating the structure and the working principle.

To achieve large motions at a low switching temperature (100~150ºC) as required for SSL applications, the actuator beam is made of narrow silicon beams coated on the two sidewalls with a large CTE material like aluminum.

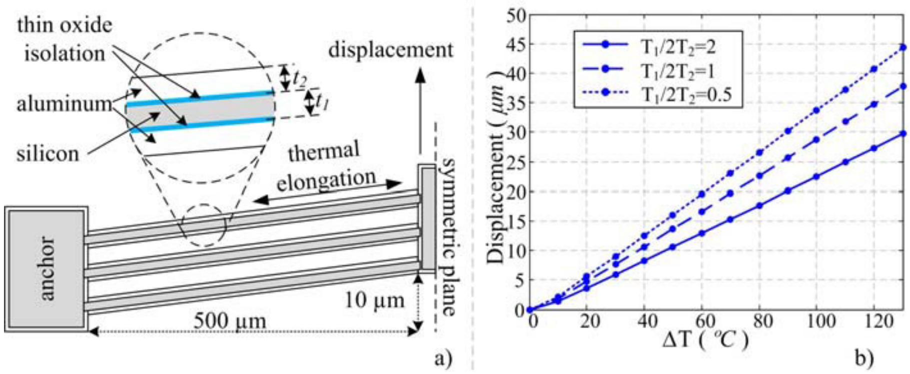


Fig. 2. (a) Layout and size of the *V*-shape actuation beam used in the analysis and fabrication (b) The motion of the contact plate as a function of temperature variation. Devices with different thicknesses of silicon and aluminum layers are calculated.

When temperature rises, the contact plate is pushed by the actuation beam against the electrodes to create an electrical contact. The triggered temperature can be designed by modifying the geometry of the device, e.g. the initial distance between the plate and the electrodes. The motion of the plate as a function of the temperature variation is calculated by using finite element analysis (Fig.2b) for different thicknesses combination of silicon (t_1) and aluminum layers (t_2). The displacement rises with the increase of the thickness ratio between aluminum and silicon layers.

3. Fabrication

A single-mask fabrication process (Fig. 3) is developed for a low-cost integration of the switch. The process is similar to single crystal reactive etching and metallization (SCREAM) [5] process. After a deep reactive-ion etching (DRIE) step defining free-standing silicon beams (Fig 3a), a thermal oxidation is performed to create a thin isolation layer on the silicon surface (Fig 3b). The width of the silicon beams was designed to be 1.5 µm. An aluminum layer (around 1.0 µm at each side of the beam) is deposited (Fig.3c) and immediately covered by a thin titanium nitride (TiN) layer to prevent oxidation of the aluminum surface for a better electrical contact.

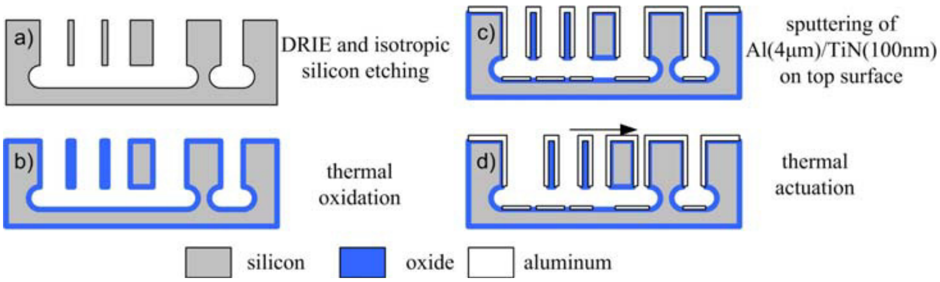


Fig. 3: Schematic drawing of the single-mask fabrication process.

4. Results

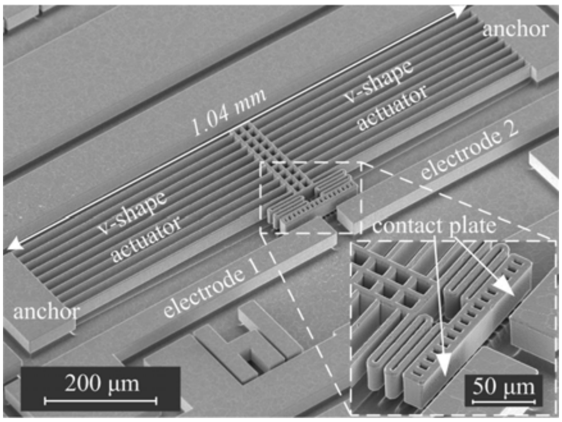
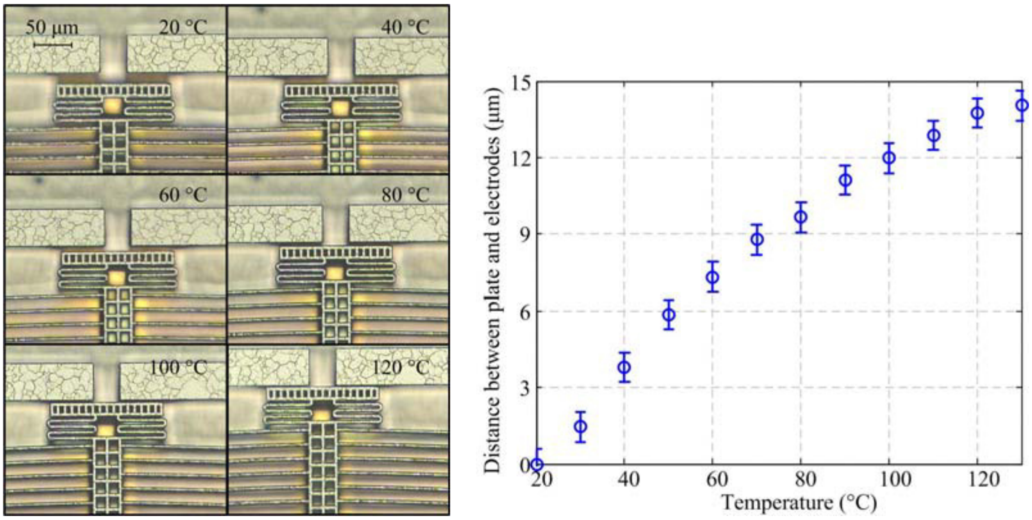


Fig. 4: SEM photo of the fabricated temperature triggered switch and a close-up photo of the contact plate.

A typical fabricated device is shown in Fig.4. The device is 1.04 x 0.4 mm^2 in size, and the height of the switch structure is 35 µm. Each actuation beam is 500 µm long and around 3.5 µm wide. The initial gap between the contact plate and fixed electrodes is 14 µm.

The TTS is tested on a probe-station with a built-in heater for temperature control. A solid contact (Fig.5) is achieved at around 130ºC, which is suitable for LED cooling control. The contact resistance is measured to be less than 2 ohm (including the contact resistance between probes and connection pads).



(a) (b)

Fig. 5: (a) Microscope images of the temperature triggered switch at different temperatures. A solid contact is achieved at 130ºC. The contact resistance is < 2 ohm. (b) Motion of the contact plate as a function of substrate temperature.

5. Conclusion

A temperature triggered MEMS switch is proposed for cooling control in SSL applications. Demonstrators are fabricated with a single-mask 3D micro-machining process. A switching temperature threshold of 130°C has been achieved with a contact resistance of < 2 ohm. It allows the automatic control of the cooling system without any need of additional, costly electronic components.

Acknowledgements

The authors would like to acknowledge the technical staff of DIMES-ICP group for their precious help and the Enlight project (http://www.enlight-project.eu/), funded by ENIAC, for the financial support.

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